# Discussion on a new model for the Hercynian Orogen of Gondwana France and Iberia by D. Shelley & G. Bossière.

Carine Cartier, Michel Faure, H. Lardeux

# Discussion on “A new model for the Hercynian Orogen of Gondwana France and Iberia” by D. Shelley & G. Bossière, Journal of Structural Geology 2000, 22, 757–776

**C. Cartier[a], M. Faure[a] and H. Lardeux[b]**

[a] ISTO – UMR6113 – CNRS – Université d’Orléans, Bâtiment Géosciences, BP 6759, 45067 Orléans Cedex 2, France
[b] Université Catholique de l'Ouest, I.R.F.A., 3 pl. A. Leroy, 49008 Angers Cedex 1, France

**Author Keywords:** Hercynian belt; Armorican Massif; Geodynamics; Thrust tectonics; Collage

# 1. Introduction

In spite of numerous studies, the geodynamic evolution of the Hercynian Orogeny of Western Europe is still controversial. In a recent paper, Shelley and Bossière (2000) propose that the Hercynian Orogeny in Iberia and France was a ‘collage’ of distinct fault-bounded ‘terranes’ developed during a major dextral wrenching of more than 2000 km. This interpretation is in line with that already proposed by Badham (1982) but is at variance with most other published models that emphazise tangential tectonics, that is to say thrusting and collision tectonics driven by oceanic and continental subduction (e.g. Matte; Ledru; Dias and Faure and references therein). The Shelley and Bossière model has been criticized for parts dealing with the Iberian branch of the orogen by Pereira and Silva (2001). In the following, we shall comment on the strike-slip model for the S. Armorican branch of the belt, on the basis of first-hand geological data aquired from the SE part of the Armorican Massif ( Cartier and Cartier) and general considerations on the Hercynian Belt.

# 2. Comments on the S. Armorican geology

The structure of the S. Armorican domain is rather complex since a wide variety of rock types are exposed in a close vicinity. By analogy with Western N. America cordillera, Shelley and Bossière (2000) present the geology of the S. Armorican domain in terms of ‘tectonostratigraphic terranes’. This presentation implicitly assumes that no link may be found between these terranes, and thus any attempts to look for tectonic horizontal superpositions and to reconstruct a geodynamic evolution based on convergent displacements are hopeless. However, as we shall try to show in the following, that an alternative interpretation exists.

Instead of ‘terrane’, the term ‘unit’, which denotes a tectonic relationship with the neighboring formations, is preferred here. The expression ‘Ancenis basin’ is also preferred to ‘Ancenis terrane’. Since Fig. 1 of Shelley and Bossière (2000) is too general, it cannot be used to present the complexity of the geology of the S. Armorican domain. We shall use a more detailed map ( Fig. 1, modified from Cartier et al., 2001). The geological outline of the S. Armorican domain as presented by Shelley and Bossière (2000) is reviewed below following these authors’ order. Moreover, the authors’ Fig. 4 presenting the lithostratigraphy of each terrane as a column independent of its neighbors does not represent well the relationships between these units. Therefore, our own interpretation of the same area in terms of tectonic superposition is provided by a general cross-section in Fig. 2.

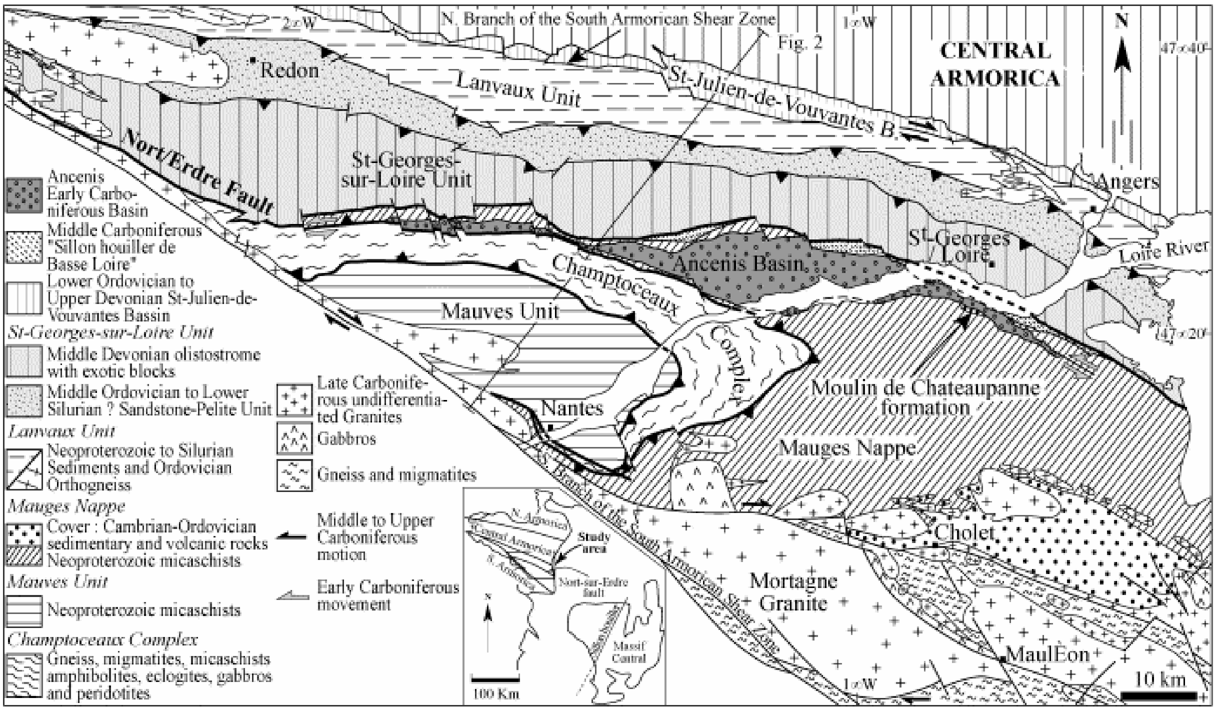


Fig. 1. Structural map of the Ligerian Domain (modified from Cartier et al., 2001) showing the tectonic superposition of flat-lying units. The final structure of the area is the result of several deformation events.

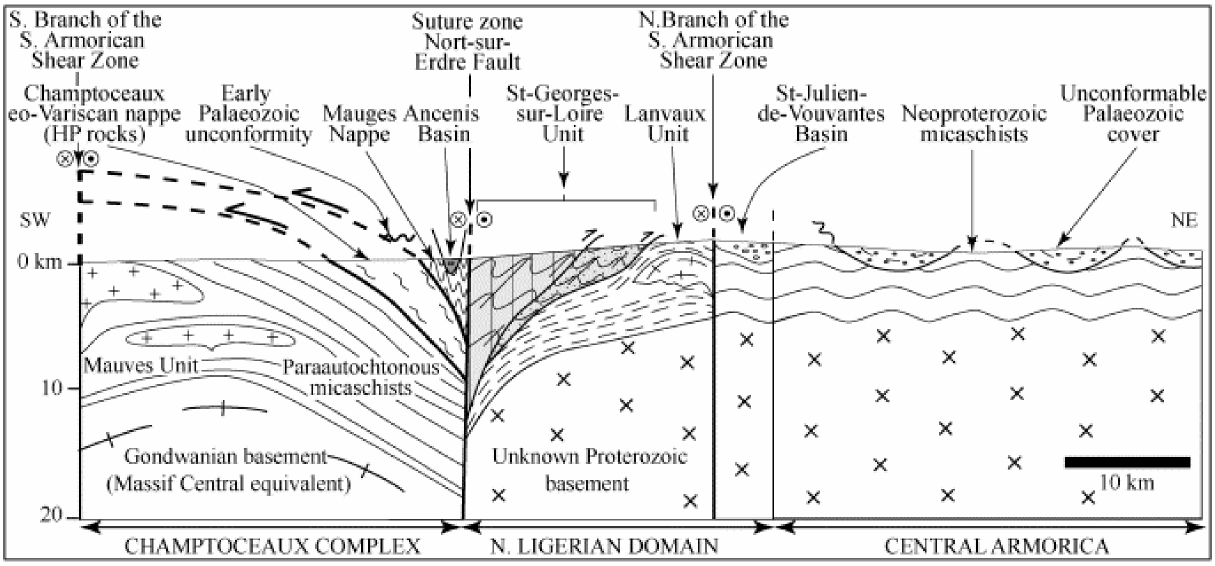


Fig. 2. Crustal-scale interpretative cross-section through the Ligerian Domain and Central Armorica located in Fig. 1. Emphasis is placed on polyphase tangential tectonics.

## 2.1. Lanvaux unit

Conversely to that indicated by Shelley and Bossière (2000), the Lanvaux orthogneisses, which outcrop discontinuously along a NW–SE trend, exhibit three clusters of Rb–Sr dates interpreted as granite emplacement ages: around 553±8 Ma (Lanvaux I granite), 474±8 Ma (Lanvaux II granite) and 433±4 Ma (Lanvaux III granite; Vidal, 1980). The country-rocks consist of metasediments ranging from Neoproterozoic to Silurian.

At the north boundary of the Lanvaux unit, Shelley and Bossière (2000) also mention the St-Julien-de-Vouvantes basin as a component of their 'Lanvaux terrane'. Indeed, the age of the St-Julien-de-Vouvantes basin is still debated ( Lardeux and Lardeux). Dubreuil and Dubreuil viewed this basin as a Dinantian olistostrome with Silurian–Devonian olistoliths in his inner part. But this interpretation is not supported by paleontological data, since all the analyzed pelitic rocks, considered as the matrix of the olistostrome provide Ordovician fossils. Another possibility is to consider the St-Julien-de-Vouvantes basin as a sedimentary trough with continuous Ordovician to Devonian deposits deformed by the Hercynian tectonics (e.g. Janjou et al., 1998). The discontinuous lensoid style of the Devonian limestone is more likely the result of the Carboniferous shearing rather than sedimentary processes.

## 2.2. St-Georges-sur-Loire unit

This domain is much complex than described by Shelley and Bossière (2000). Two sub-units are recognized ( Ledru; Cartier and Cartier; Fig. 1). Namely: (i) a northern sub-unit formed by sandstone–pelite alternations, and (ii) a southern sub-unit, which is an olistostrome with various blocks, such as Silurian black cherts (or phtanites), Upper Silurian to Middle Devonian limestones, mafic volcanics (including pillow lavas, gabbro, volcano-sedimentary breccias), and acidic rhyolitic volcanics and microgranites. The age of the matrix is unknown but it cannot be older than Middle Devonian, which is the age of the youngest limestone block. Both sub-units exhibit a flat lying cleavage and N–NW verging folds. The olistostrome unit overthrusts to the north the northern sub-unit ( Cartier and Cartier). The whole St-Georges-sur-Loire unit overthrusts the Lanvaux unit ( Cavet et al., 1986; Fig. 2) and not the reverse as said by Shelley and Bossière (2000). The southern boundary of the St-Georges-sur-Loire unit is the subvertical Nort-sur-Erdre fault. To the South, Neoproterozoic low grade micaschists belonging to the Mauges nappe crop out ( Fig. 1).

## 2.3. Ancenis basin

Shelley and Bossière (2000) reject the former interpretation that this basin formed as a left-lateral pull apart ( Diot and Blaise) on the basis of stable shelf sequence sediments. However, there appears to be some misunderstanding of the regional geology. Indeed, it is important to distinguish two types of sedimentary rocks in the Ancenis basin. Firstly, Ordovician sandstone, such as that observed in the 'Moulin de Chateaupanne Formation' ( Fig. 1) crops out along the southern margin of the Ancenis basin and unconformably covers the Mauges nappe (e.g. Blaise and Lardeux; cf. below). Secondly, Devonian limestones are olistoliths resedimented into an Early Carboniferous (Tournaisian to Visean) terrigeneous matrix ( Dubreuil, 1986). The Ordovician terrigeneous rocks belong to the Paleozoic cover unconformably deposited upon Precambrian metamorphic rocks before the onset of the Hercynian orogeny. Conversely, the source area of the Devonian olistoliths is still unknown, however, it is likely located south of the Ancenis basin.

From the structural point of view, the cartographic spindle shape of the Ancenis basin and microtectonics (vertical brittle faults with horizontal slickenlines) support the left-lateral pull-apart model of Diot and Blaise (1978). Thus, the Early Carboniferous Ancenis basin is a syntectonic sedimentary trough superimposed upon already structured units.

## 2.4. Coal trough

Middle Carboniferous (Namurian) coal bearing sandstone (called 'Sillon Houiller de Basse Loire'; Fig. 1) discontinuously crops out between the Ancenis and the St-Georges-sur-Loire unit. Due to the late Carboniferous dextral wrenching these formations are highly sheared in a brittle regime ( Diot and Blaise, 1978). This fact shows that a part, but not the whole, of the deformation occurred in Middle and Late Carboniferous and overprints earlier structures.

## 2.5. Champtoceaux Complex and Mauves (para-autochthonous) unit

As stated above, the terms 'Champtoceaux terrane, Mauves-sur-Loire terrane and Mauges terrane' are ambiguous and unsatisfactory because they suggest that these lithologic and tectonic units are unrelated to each other. But as demonstrated before (e.g. Marchand and Ball) these units form a stack of nappes ( Fig. 1 and Fig. 2).

The Mauves-sur-Loire unit consists of greenschist facies micaschists, which are correlated to the Lower unit of the nappe stack in the French Massif Central. The Mauves-sur-Loire unit is overthrust by the Champtoceaux complex, which is made of several sub-units distinguished on the basis of their lithology and metamorphic grade. It is worth noting that within the Champtoceaux complex, mafic eclogites, HP orthogneiss, quartzite and ultramafics record pressure conditions higher than 20 kbar (Ballèvre et al., 1994). This fact clearly demonstrates that the S. Armorican continental crust did not experience wrenching alone, but also subduction up to 60 km depth and subsequent exhumation.

## 2.6. Mauges nappe

This unit consists of Neoproterozoic micaschists unconformably overlain by Cambrian terrigeneous rocks with volcanogenic clasts and rhyolites (near Cholet; Fig. 1; Cavet et al., 1966) or by Ordovician sandstone (i.e. Moulin de Chateaupanne Formation; Fig. 1) along the S. margin of the Ancenis basin ( Blaise et al., 1970, cf. Section 2.3). As observed S. of the Loire river, the micaschists overthrust the Champtoceaux complex. Moreover, those micaschists also crop out N. of the Loire river where they surround the Ancenis basin. The Mauges nappe is therefore a basement nappe overthrust upon the continental and oceanic derived formations of the Champtoceaux complex ( Fig. 2).

To the South, the stack of nappes is abruptly interrupted by the S. branch of the S. Armorican Shear Zone. Obviously, this dextral ductile fault is a late structure superimposed upon thrust related flat lying structures. The activity of the S. Armorican shear zone is dated as Middle Carboniferous age (Namurian–Westphalian, ca. 325–315 Ma) by the synkinematic leucogranites (Le Corre et al., 1991).

### 2.7. Mortagne granite

Among the Carboniferous leucogranites, the Mortagne pluton exhibits typical structures related to dextral wrenching. The left-lateral pull-apart model proposed for the emplacement of this massif (Guineberteau et al., 1987) is not supported by field data. One may also question the usefulness of using the terrane concept just to present a leucogranite pluton and its host rocks.

# 3. Discussion

### 3.1. On the S. Armorican events

Without denying the reality of strike slip faults and the major role they play in the final structure of the S. Armorican domain, it appears to us that such a wrenching is a minor process in the whole orogenic evolution of the Hercynian Belt. Indeed, demonstrated displacement along each fault is weak: 40 km along the northern branch of the S. Armorican shear zone and 15 km along the N. Armorican shear zone (Jégouzo and Rosselo, 1988). Thus, saying that the offset might be several hundred kilometers is, in the present state of knowledge, purely speculative.

Another very important point, is that Middle to late Carboniferous right lateral wrenching is preceeded by Early Carboniferous (Tournaisian–Visean) left-lateral wrenching. Several lines of evidence support this view. Namely, (i) the syntectonic infill of the Ancenis basin, (ii) the top-to-the-NW ductile shearing along flat-lying foliation within the St-Georges-sur-Loire unit (Cartier and Cartier), and (iii) the polyphase sinistral then dextral shearing in the Lanvaux unit ( Cogn and Faure). Lastly, before the wrenching displacements, several tangential synmetamorphic tectonic events took place in the Hercynian Belt. However, due to these polyphase strike-slip deformations, the early events are difficult to decipher in the Armorican Massif but can be better analyzed in the Massif Central.

### 3.2. On the Massif Central tectonics

At the scale of the French Hercynian orogen, Shelley and Bossière (2000) separate a ‘Massif Central terrane’ corresponding to the metamorphic stack of nappes (e.g. Ledru et al., 1989) and a ‘southern terrane’ that includes the weakly metamorphic Paleozoic sequences observed in the Montagne Noire in S. Massif Central. In the Massif Central, the metamorphic nappes exhibit a northward dipping low angle foliation and overthrust the metamorphic series. Thus the boundary of these two units is not a subvertical strike-slip fault. Although hidden below Mesozoic sedimentary rocks, the existence of a high-angle fault separating these two units is extremely speculative. These two ‘terranes’ mainly differ by their metamorphic grade, but they both belong to the N. margin of Gondwana, therefore, the distinction of two ‘tectonostratigraphic terranes’ does not appear necessary to give a better understanding of the tectonic evolution of the orogen.

# 4. Conclusion

In the strike-slip model presented by Shelley and Bossière (2000), two points seem, to us, underestimated. Firstly, at the scale of the Hercynian orogen, flat lying foliations spread out over hundreds of square kilometers. Such a structural feature, which is very common in collision orogens, has been well explained for a long time, as the result of a crustal scale low angle ductile shear zone (e.g. Mattauer, 1975). Even if strike-slip faults are important structures in the Armorica–Iberia orocline, lithospheric convergence accomodated by continental subduction at mantle depths and subsequent exhumation of deeply metamorphosed continental crust play the major geodynamic role in the formation of the Hercynian Belt.

Secondly, the authors did not sufficiently take into consideration the importance of polyphase tectonics and the timing of deformations. Indeed, several lines of evidence suggest that the Paleozoic geodynamic evolution of Western Europe results from several periods of lithospheric rifting and convergence (e.g. Faure et al., 1997). In the present state of knowledge, belt parallel strike slip displacements of moderate amplitude (i.e. less than 100 km) occur only in the late stages of continental convergence in Carboniferous times. At that time, crustal scale subhorizontal shearing and continental collision, which are responsible for most of the synmetamorphic structures, were already completed.

# References


Badham, 1982. J.P.V. Badham , Strike-slip orogens: an explanation for the Hercynides. *Journal of Geological Society London* (1982), pp. 439–504.

Ballèvre et al., 1994. M. Ballèvre, J. Marchand, G. Godard, J.C. Goujou and R. Wyns , Eo-Hercynian events in the Armorican Massif. In: J.D. Keppie, Editor, *Pre-Mesozoic Geology in France and Related Areas*, Springer-Verlag, Berlin (1994), pp. 183–194.

Blaise et al., 1970. J. Blaise, P. Cavet and H. Lardeux , Les relations entre le Briovérien et le Paléozoïque sur la rive gauche de la Loire entre Saint-Florent-le-Vieil et Chalonnes (Maine-et-Loire, Sud-Est du Massif armoricain). *Bulletin de la Société Géologique de France* **12** (1970), pp. 5–14.

Cartier et al., 2000. Cartier, C., Faure, M., Lardeux, H., 2000. La partie orientale du bassin de St-Georges-sur-Loire (Massif Armoricain): un olistostrome à blocs exotiques. Abstract of Proceedings, 18$^{e}$ Réunion des Sciences de la Terre, Paris, 17–20 Avril 2000, p. 101.

Cartier et al., 2001. C. Cartier, M. Faure and H. Lardeux , The Hercynian Orogeny in the South Armorican Massif (Saint-Georges-sur-Loire Unit, Ligerian Domain, France): rifting and welding of continental stripes. *Terra Nova* **13** (2001), pp. 143–149.

Cavet et al., 1966. P. Cavet, M. Gruet and J. Pillet , Sur la présence du Cambrien à Paroxides à Cléré-sur-Layon (M.-et-L.), dans le Nord-Est du bocage Vendéen (massif armoricain). *Comptes Rendus de l'Académie des Sciences Paris* **263** (1966), pp. 1686–1688.

Cavet et al., 1986. P. Cavet, M. Dubreuil, J. Blaise and S. Willefert , Les ampélites du Houx (Silurien), leurs relations avec les unités paléozoïques de Lanvaux-Les-Ponts-de-Cé et Saint-

Georges-sur-Loire (Massif Armoricain). *Bulletin de la Société des Sciences Naturelles de l'Ouest de la France* **8** (1986), pp. 136–143.

Cogné et al., 1983. J.P. Cogné, P. Choukroune and J. Cogné , Cisaillements varisques superposés dans le Massif de Lanvaux (Bretagne centrale). *Comptes Rendus de l'Académie des Sciences Paris* **296** (1983), pp. 773–782.

Dias and Ribeiro, 1995. R. Dias and A. Ribeiro , The Ibero–Armorican arc: a collision effect against an irregular continent?. *Tectonophysics* **246** (1995), pp. 113–128.

Diot and Blaise, 1978. H. Diot and J. Blaise , Etude structurale dans le Précambrien et le Paléozoïque de la partie méridionale du domaine ligérien (SE du Massif armoricain): Mauges, synclinal d'Ancenis et sillon houiller de basse Loire. *Bulletin de la Société Géologique et Minéralogique de Bretagne* **X** (1978), pp. 31–50.

Dubreuil, 1986. Dubreuil, M., 1986. Evolution géodynamique du Paléozoïque Ligérien (Massif Armoricain). Thèse d'Etat, Université de Nantes.

Dubreuil, 1987. M. Dubreuil , Le bassin en décrochement de Saint-Julien-de-Vouvantes-Angers (Carbonifère inférieur du Sud-Est du Massif armoricain). *Bulletin de la Société géologique de France* **8** (1987), pp. 215–221.

Faure and Cartier, 1998. M. Faure and C. Cartier , Déformations ductiles polyphasées dans l'antiforme orthogneissique de St-Clément-de-la-Place (unité de Lanvaux, Massif armoricain). *Comptes Rendus de l'Académie des Sciences Paris* **326** (1998), pp. 795–802.

Faure et al., 1997. M. Faure, C. Leloix and J.Y. Roig , L'évolution polycyclique de la chaîne hercynienne. *Bulletin de la Société géologique de France* **168** (1997), pp. 695–705.

Guineberteau et al., 1987. B. Guineberteau, J.L. Bouchez and J.L. Vigneresse , The Mortagne granite pluton (France) emplaced by pull-apart along a shear zone: structural and gravimetric arguments and regional implication. *Geological Society of America Bulletin* **99** (1987), pp. 763–770.

Janjou et al., 1998. Janjou, D., Lardeux, H., Chantraine, J., Callier, L., Etienne, H., 1998. Notice explicative, carte géol. France (1/50000), feuille de Segré (422)—Orléans: Bureau de recherches géologiques et minières, 68p. Carte géologique par D. Janjou et coll. (1998).

Jégouzo and Rosselo, 1988. P. Jégouzo and A.E. Rosselo , La Branche Nord du Cisaillement Sud–Armoricain (France): un essai d'évaluation du déplacement par l'analyse des mylonites. *Comptes Rendus de l'Académie des Sciences Paris* **307** (1988), pp. 1825–1831.

Lardeux, 1969. H. Lardeux , Le Dévonien du synclinal de Saint-Julien-de-Vouvantes (Sud-Est du Massif armoricain). Etat des recherches et précisions nouvelles. *Bulletin de la Société d'études Scientifiques de l'Anjou* **7** (1969), pp. 3–40.

Lardeux, 1998. H. Lardeux , La formation des Maisons Rouges, unité stratigraphique d'âge Dévonien inférieur du domaine Ligérien, sud-est du Massif Armoricain. *Bulletin de la Société Scientifique d'Anjou* **16** (1998), pp. 79–88.

Lardeux and Cavet, 1994. H. Lardeux and P. Cavet , Palaeozoic of the Ligerian domain. In: J.D. Keppie, Editor, *Pre-Mesozoic Geology in France and Related Areas*, Springer-Verlag, Berlin (1994), pp. 152–156.

Le Corre et al., 1991. C. Le Corre, B. Auvray, M. Ballevre and M. Robardet , Le Massif Armoricain. In: A. Piqué, Editor, *Massifs Anciens de France*, Sciences Géologiques, Strasbourg (1991), pp. 31–103.

Ledru et al., 1986. P. Ledru, A. Marot and Y. Herrouin , Le synclinorium de Saint-Georges-sur-Loire: une unité ligérienne charriée sur le domaine centre armoricain. Découverte de métabasite à glaucophane sur la bordure de cette unité. *Comptes Rendus de l'Académie des Sciences Paris* **303** (1986), pp. 963–968.

Ledru et al., 1989. P. Ledru, J.M. Lardeaux, D. Santallier, A. Autran, J.M. Quenardel, J.P. Floc'h, G. Lerouge, N. Maillet, J. Marchand and A. Ploquin , Où sont les nappes dans le Massif Central français?. *Bulletin de la Société géologique de France* **8** (1989), pp. 605–618.

Marchand, 1981. J. Marchand , Ecaillage d'un “mélange tectonique” profond: le complexe cristallophyllien de Champtoceaux (Bretagne Méridionale). *Comptes Rendus de l'Académie des Sciences Paris* **293** (1981), pp. 223–228.

Mattauer, 1975. M. Mattauer , Sur le mécanisme de formation de la schistosité dans l'Himalaya. *Earth and Planetary Science Letters* **28** (1975), pp. 144–154.

Matte, 1986. P. Matte , La chaîne varisque parmi les chaînes paléozoïques péri-atlantiques, modèle d'évolution et position des grands blocs continentaux au Permo-Carbonifère. *Bulletin de la Société géologique de France* **8** (1986), pp. 9–24.

Pereira and Silva, 2001. M.F. Pereira and J.B. Silva , A new model for the Hercynian Orogen of Gondwana France and Iberia: discussion. *Journal of Structural Geology* **23** (2001), pp. 835–838.

Shelley and Bossière, 2000. D. Shelley and G. Bossière , A new model for the Hercynian Orogen of Gondwana France and Iberia. *Journal of Structural Geology* **22** (2000), pp. 757–776.

Vidal, 1980. Vidal, P., 1980. L'évolution polyorogénique du Massif armoricain: apport de la géochronologie et de la géochimie isotopique du strontium. Mémoire de la Société géologique et minéralogique de Bretagne, 21, Université de Rennes.